POST GRADUATE CERTIFICATE IN ANTARCTIC STUDIES 2014/2015

Supervised Project

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"The Potential for Solar Power at Scott Base"

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ABSTRACT

Antarctica is the most remote continent on earth, with only 4000 people there in the summer months. Despite the lack of people, energy demand is extremely high. The Antarctic Treaty System encourages the use of renewable energy, and forms such as wind and solar energy are reasonably common in Antarctica. As New Zealand is a leader in sustainability and ethical operations in the Antarctic, an investigation into the use of solar energy (photovoltaic system) was undertaken. It was found that by implementing 408, 130 Watt photovoltaic panels, up to 46.5 Mega-Watt hours could be produced at Scott Base from September-March. Whilst this is a substantial amount of energy, wind turbines are a more feasible option due to ground space requirements and increased energy production. A small investigation into the use of photovoltaic systems at Cape Bird was undertaken. It was found that photovoltaic systems are a very feasible option for field camps and should be investigated further. It is recommended that investigations are undertaken to determine the feasibility of solar thermal and solar hot water systems at Scott Base.

List of abbreviations used:

PV: Photovoltaic

MWh: Mega Watt hours

kWh: kilo Watt hours

V:Volts

kVA: Kilovolt-ampere

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1.0 INTRODUCTION

Antarctica is the coldest and least populated of all of the continents, with an area over 50% greater than the United States of America. Less than 1% of the Antarctic continent is ice free, with the rest covered by glacial ice, nearing 4000m thick in certain places (Tin, et al., 2010). The Antarctic plateau, with average heights of nearly 3000m above sea level, averages a year round temperature of -50°C, and is also home to the lowest recorded temperature in nature of -89.2°C at Russia's Vostok Station (Tin, et al., 2010).

Despite the isolation of Antarctica, the continent is still home to approximately 1000 people in the winter, and over 4000 people in the summer, distributed across the 75 active research stations, as of 2009 (Tin, et al., 2010) (Figure 1; Figure 2). Energy in Antarctica is used almost exclusively for heat and electrical power at scientific research bases, with electricity generators being used for lighting, space heating, water purification/pumping and waste systems (Stone, 2013). Gasoline, diesel and jet fuel are used to facilitate scientific field operations and transport to, from and within the continent. Antarctica provides an almost unlimited source of renewable energy, through persistent strong winds and months of high solar radiation levels.

Renewable energy in Antarctica is becoming increasingly more important and utilized more frequently. As fossil fuels are a finite resource, the use of them is becoming a confronting and pressing issue for countries worldwide, particularly as the demand for such energy sources are increasing and the environmental effects of utilising these fossil fuels becomes evident. Alternative, renewable energy sources are consequently a priority for the worldwide community. As some stations in Antarctica are inaccessible by sea for over 9 months of the year, a single resupply ship visit is often the predominant source for the resupply of food, fuel and maintenance equipment (Tin, et al., 2010). This process can be severely delayed or even cancelled in a season with unusually thick sea ice, which illustrates a need for secondary power sources, should a fuel delivery not be made.

According to the Environmental Protocol, part of the Antarctic Treaty, states that Antarctica is a natural reserve, devoted to peace and science. Vested states in Antarctica have a moral obligation to maintain Antarctica's natural state, as is illustrated in Article 3 (appendix 1) of the Environment Protocol which state that protection of the Antarctic environment as a wilderness with aesthetic and scientific value shall be a "fundamental consideration" of activities in the area. This further demonstrates the requirement for renewable energy sources in Antarctica.

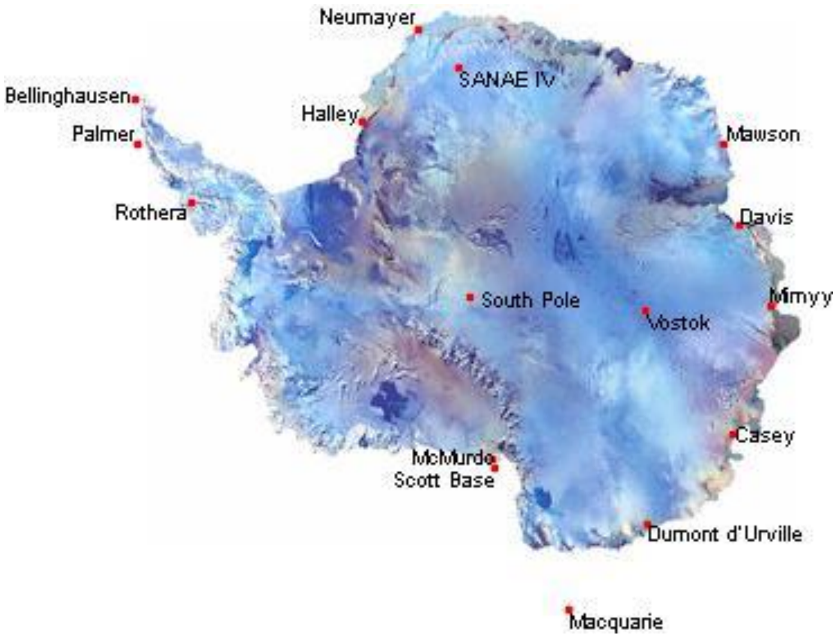

Figure 1: Research stations in Antarctica (not exhaustive). Source: http://www.antarcticconnection.com/shopcontent.asp?type=stations-index

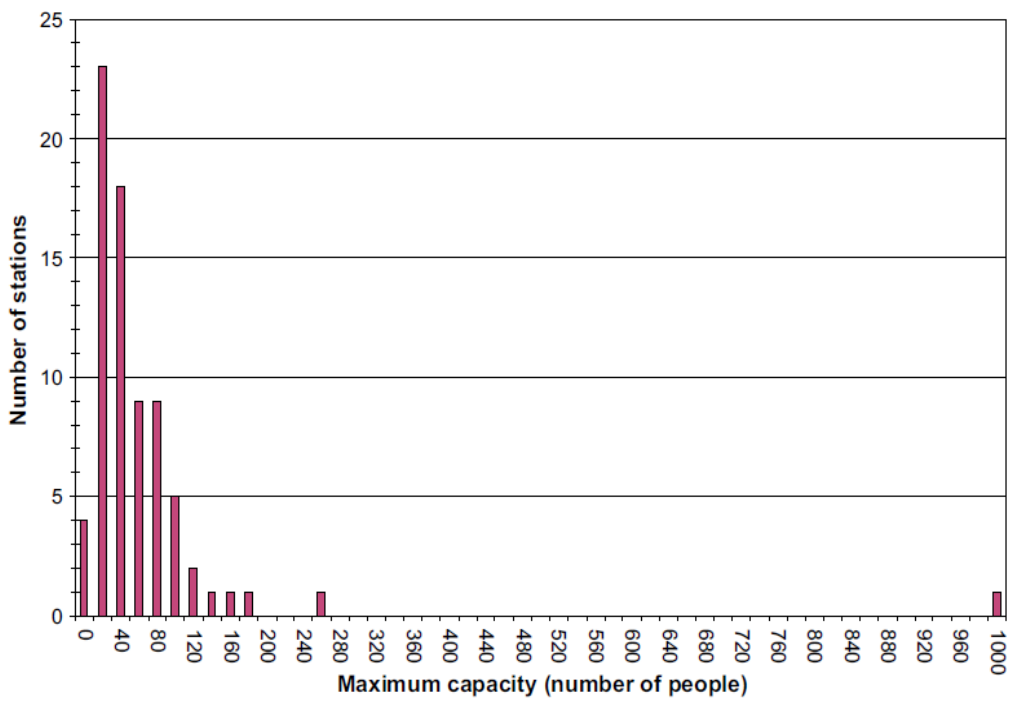

Figure 2: Capacity of stations in Antarctica (Tin, et al., 2010).

1.2 Aims & Methods

There has been some excellent progress in recent years, demonstrating the feasibility of renewable energy production in Antarctica. This report will determine if it is possible to further minimise the use of diesel generators in the summer months at Scott Base, and will draw on case studies from other bases in Antarctica. As Scott Base already has a wind farm, solar energy will be the primary focus. The current limitations of implementing solar at Scott Base will be explored and possible methods to overcome these limitations will be considered. This report will also take into account the costs involved with implementing solar and will calculate the return time on the investment. The costs of the solar system will be determined by obtaining quote from a private company. The costs of running the diesel generators currently used at Scott Base will be calculated and future usage costs will be calculated using past usage levels and past diesel costs.

As New Zealand strives to be the leaders in Antarctic operations, and Antarctica NZ aspires to act with the highest operational and environmental standards, investigation into minimizing any impact from Scott Base is required. The context of this report should be viewed with regard to the Statement of Performance Expectations (2014/2015), in particular pages 10-11, Environmental Stewardship. As a continent, Antarctica may be the best place to set the standard of renewable energy use. If bases in Antarctica, one of the harshest environments on earth, can be near self-sufficient, it should inspire the rest of the world to make use of such renewable resources.

2.0 HISTORY OF ENERGY USE AND GENERATION IN ANTARCTICA

Heat and energy generation is a requirement for survival and has been a necessity since the first permanent and semi-permanent structures in Antarctica. The first space heating processes in Antarctica occurred in the heroic era, where seal and penguin blubber was harvested and burnt in huts, built by the parties (Shackelton, 2001). The burning of this blubber was favourable at the time, as it was readily available and free, though it did result in a greasy film on the surfaces on the hut, which had an unpleasant odour. Coal was also used, up until the Scientific Era, when most activities in Antarctic became dependent on other forms of fossil fuel. Coinciding with the International Geophysical Year, many scientific stations came into prominence, most relying almost solely on the use of diesel (Spinks, 1992). Diesel generators have provided the vast majority of all energy in Antarctica, with all bases relying on them in the early days of permanent scientific bases. McMurdo (prior to the installation of the Ross Island Wind Farm) used over 5million litres of fuel annually for electricity production alone (Tin, et al., 2014).

2.0.1 Issues with diesel/fossil fuel usage

Given the pristine nature of Antarctica, delicate handling and use of fossil fuel is required. There are many risks associated with the use of fossil fuels in such a fragile location, such as disposal of used fuel barrels. This has been an ongoing issue, for example in 1963 at McMurdo station, over 400 used and discarded barrels were collected, even though significant time had passed since their initial disposal (Harrowfield, 1997). Another example is from Hallett Station, where in 1983, 134 discarded fuel drums were identified, and a leaking seal from a 380,000 litre fuel tank (Figure 3) was identified, which were the causes of significant fuel seepage into the surrounding snow and soil, posing a threat to the wildlife in the area (Pascoe, 1983). The cost involved to supply a small population in an extremely isolated region with fossil fuels is immense, with the point of use cost being approximately three times the purchase price (Olivier, et al., 2007)

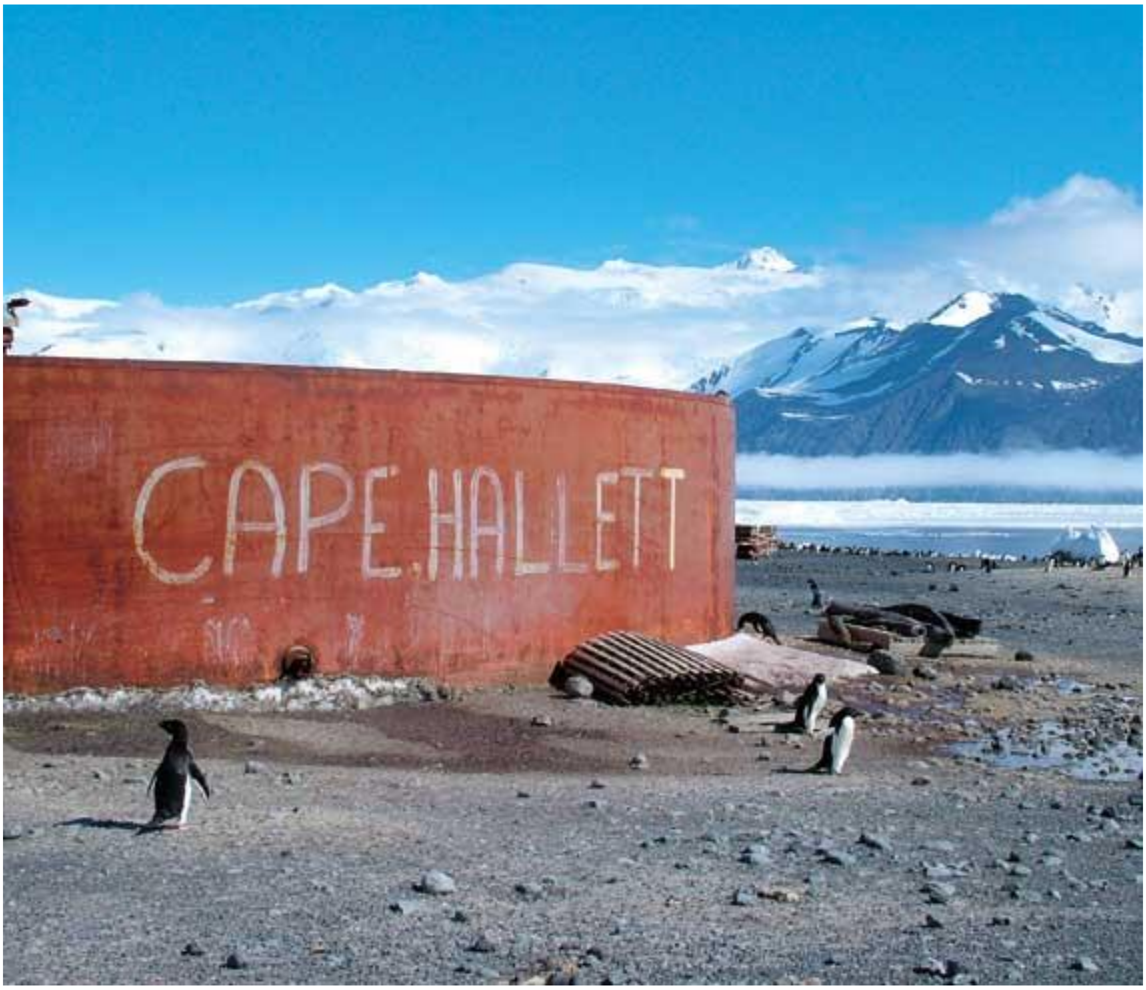

Figure 3: 100,000 Gallon fuel tank and Cape Hallett Station that was leaking into the surroundings. Rebecca Roper Gee (http://nzlifeandleisure.co.nz/cape-hallett-station/)

2.0.2 History of power generation at Scott Base

When Scott Base opened in 1957, six 6kVA generators powered the electrical load and heating (Harrowfield, 1997; Calder-Steele, 2012). In the early 1960's, a 48kVA system was implemented and in 1966 this was upgraded again to two 65kVA generators. In order to support a larger base population and the need to maintain a permanent presence resulted in many parts of the base being completely remade. In 1978 the power generation system was upgraded to a 135kVA system, and again in 1986 to a 180kVA system.

In 2009, the Ross Island Wind Farm was installed. Located on Crater Hill, between Scott Base and McMurdo Station where the average wind speed ranges from 7.9m/s to 28.4m/s, the wind farm provides continuous, sustainable energy to both Scott Base and McMurdo station (Meridian Energy LTD, 2011). The wind farm consists of three 330kW wind turbines, with a height of 37m each. The wind farm has reduced annual fuel consumption by up to 465,000 litres, demonstrating the financial and logistical benefit of utilizing renewable energy sources.

2.0.3 The potential for solar energy in Antarctica

Antarctica has an almost unlimited supply of renewable energy from both wind all year round and solar in the summer months. For example, many places in Antarctica receive 40% more sun than a Dutch summer (Van Rattinghe, 2008). This is due to the fact that the vast majority of the continent lies within the Antarctic Circle, resulting in 24 hours in sun for some months of the year, depending on latitude. Solar energy has historically not been used extensively primarily due to the large transport costs associated with getting them to the Antarctic however, as the focus shifts towards environmental stewardship it is expected that solar energy will become extensively used in the Antarctic (Prosek et al., 2013). Mason (2007) compared the solar energy received at South Pole Station to two of the world's best sites for solar energy production. Whilst the sun does not rise above the horizon for 6 months of the year at South Pole Station, the solar energy received there in the summer months is significantly higher than the two other sites (Serpa, Portugal and San Luis Valley, Colorado) (Fig. 4).

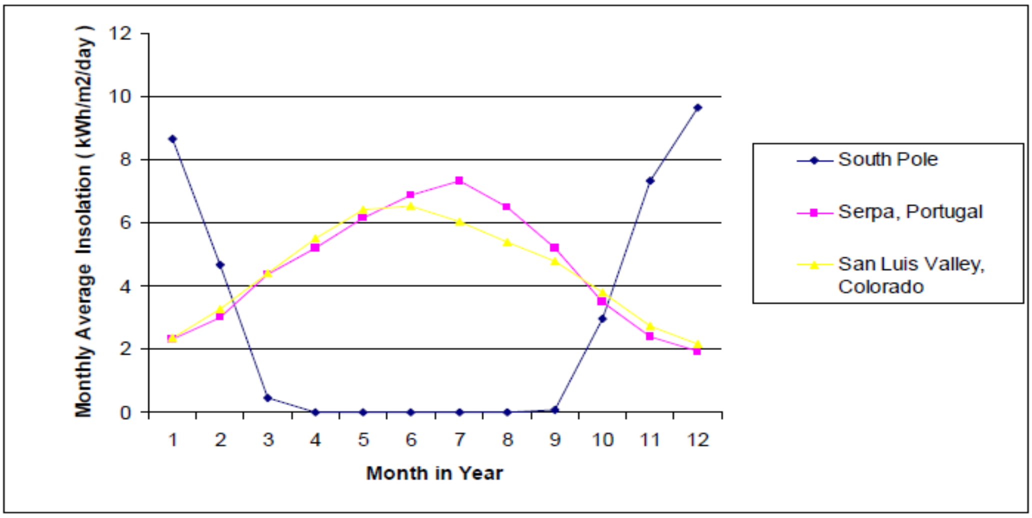

Figure 4: Monthly average insolation at South Pole Station, Serpa and San Luis Valley. Adapted from Mason, 2007.

From figure 4 it is clear that there is potential for the use of solar energy production in Antarctica. Whilst in the case it is South Pole Station, it is considered to be reasonably representative of Scott Base.

Due to the low temperatures and the reflection of radiation on the snow (albedo of 0.8), it has been found that PV array currents can be up to 20% higher than specified outputs, therefore the peak power of solar arrays in Antarctica is estimated to be approximately 120% of the peak power at Standard Test Conditions (Van Rattinghe, 2008).

There are limitations and problems associated with the used of photovoltaic panels in the Antarctic. The most obvious one is the winter darkness, however other factors include snow accumulation and dirt accumulation on the panels as well as icing of the panels (Boström, 2011). Snow accumulation and icing of solar panels is unlikely to last for an extended period of time due to the dark colour of the arrays. Aside from winter darkness, these issues can be overcome by carefully maintaining the panels, with regular checks on their condition.

3.0 CASE STUDIES

A brief case study is provided for various research stations in Antarctica, particularly those that make use of photovoltaic solar energy.

3.1 Wasa Station

At the Swedish station, Wasa (Figure 5), the majority of energy needs are met from photovoltaic cells, and solar thermal energy is used to provide space and water heating. Wasa station is situated in Queen Maud Land, at 73°03'S 13°25'W.It was built in 1989 and is relatively small, with a summer population of 30 people, and is closed from late February until November. At Wasa station, 48 small solar panels ($12m^2$ total) provide the energy required for the majority of the season, with generators only used very early and very late in the summer season if conditions become too cold. The energy is stored in 80 1.2 V nickel cadmium batteries located underneath the building (Papworth, 2002). This provided 12, 24 and 220 V power to the station through the use of a power inverter. Each panel (with a nameplate capacity of 55W) are continuously blasted by Antarctic winds, containing fine grains of gravel and ice which degrade the panels' performance. They are maintained and overall work very well (Tin, et al., 2010). The energy saving and renewable energy initiatives implemented at Wasa station have resulted in very low fuel consumption levels. Over a period of 7 weeks, the station only used 300kg of LPG and 28L of petrol (Papworth, 2002).

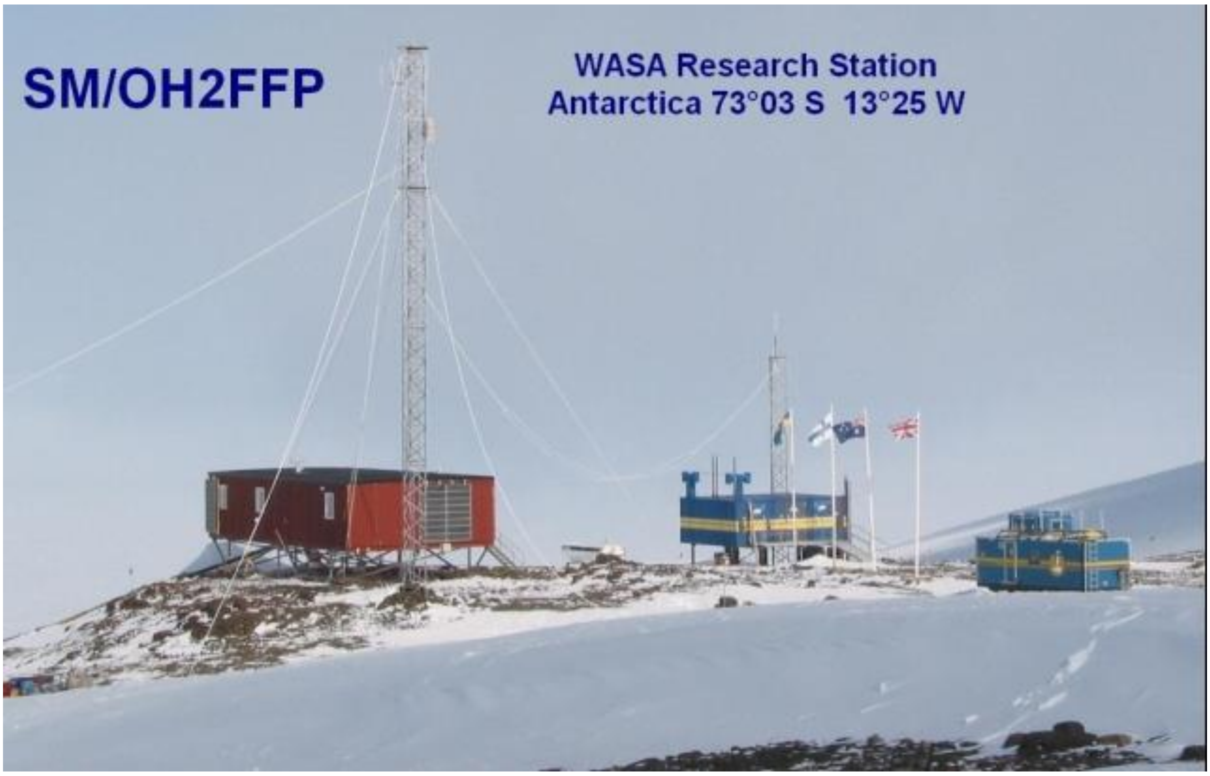

Figure 5: The Swedish Wasa Station, with solar panels visible. Source: http://french-polar-team.fr/SM_Wasa_Station_Antarctica.php

3.2 Syowa Station

Japans Syowa station (69°00’15.6”S 39°34’48.9”E, Fig. 6) is a relatively large station, housing up to 110 people over summer, and 28 in winter. A 55kW array of solar panels provides approximately 44,000kWh (44MWh) of energy per year. The panels are also equipped with air-type solar collectors which capture heat from the sunlight and transfer it to the walls of the facility. This combination reduces fossil fuel consumption by approximately 3-5% per year (Tin, et al., 2010). The station is also equipped with a solar hot water system that utilizes evacuated glass tubes to heat water in the summer months. This system can heat water from 0°C-30°C within one minute.

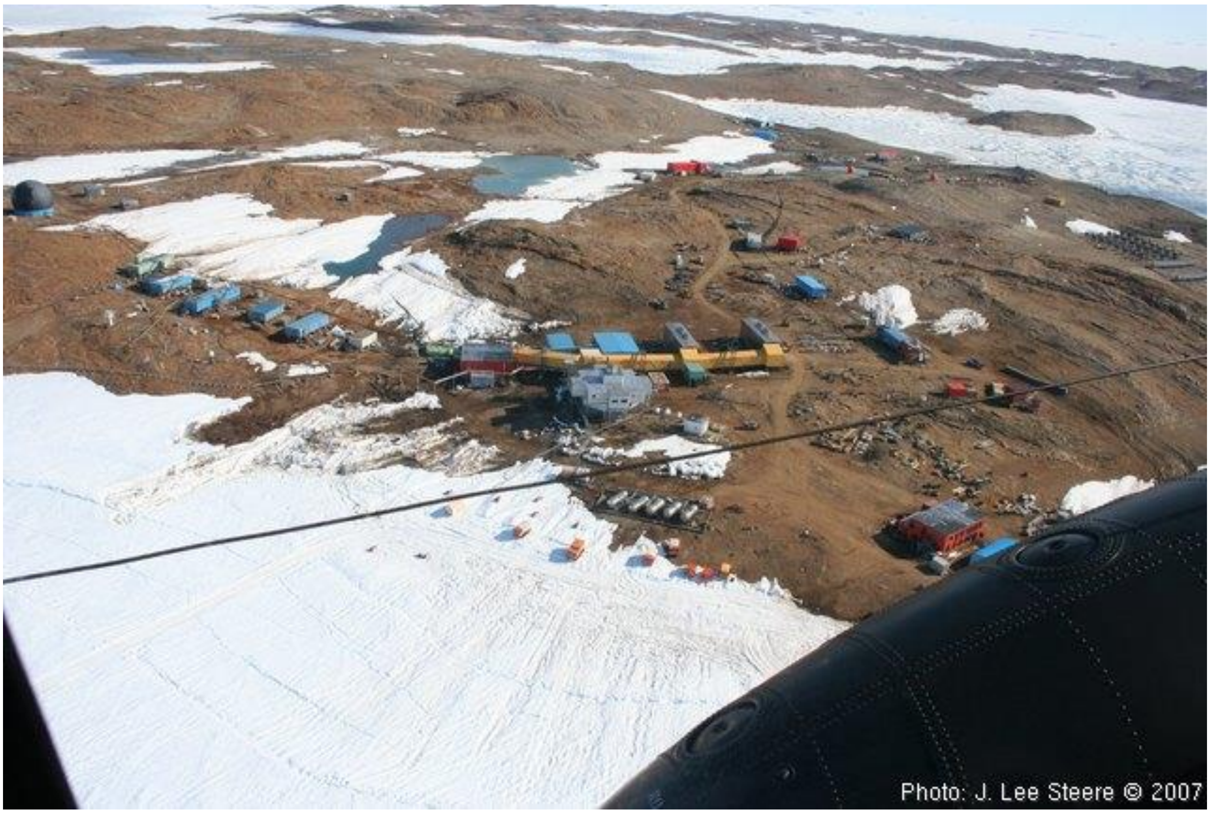

Figure 6: Syowa Station with solar panels visible on the far right. Source: http://www.antarctica.gov.au/about-antarctica/history/exploration-and-expeditions/modern-expeditions/this-week-in-antarctica/2007/air-support-this-season

3.3 Australian Antarctic Division

The bases that operate as part of the Australian Antarctic Division are mainly powered by diesel generators and wind energy (Figure 7), however a small amount of solar power is used for powering repeaters and remote radio installations, as well as some field camps (AAD, 2010). Currently, use of PV technology with the Australian Antarctic Division is minimal.

Figure 7: Australia's Mawson station, with a large wind turbine supplying most of the energy. Source: http://www.antarctica.gov.au/living-and-working/stations/mawson/living

3.4 British Antarctic Survey

Three British Antarctic Survey bases have been fitted out with solar energy systems that heat air and hot water. The largest of which is at Rothera station on the Antarctic Peninsula. The system consists of 36 solar panels, each containing 16 evacuated tubes (Figure 8). It is estimated that these fittings will save over 1000L of fuel each year. The British Antarctic Survey also used photovoltaic panels for field camps (British Antarctic Survey, 2015).

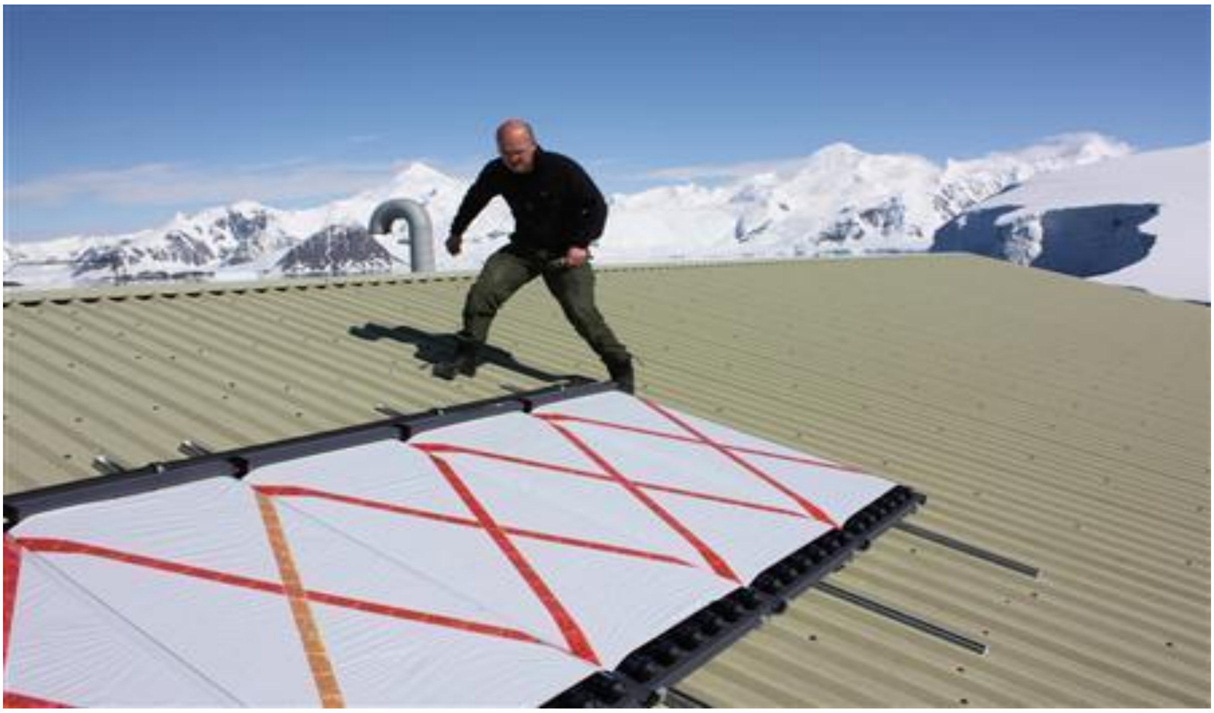

Figure 8: Solar Panels being installed at Rothera Station. Source: http://www.reuters.com/article/2009/01/20/us-antarctica-renewables-idUSTRE50J1X120090120

3.5 South Pole Station

The South Pole Station relies primarily on fuel delivered on the LC-130 Hercules aircraft (Mason, 2007). A small trial of photovoltaic technology was undertaken in 2008, using mono-crystalline NT-R5E3E 175 W Sharp panels with anti-reflective coating and BSF (Back Surface Field) structure to improve cell efficiency. Test's prior to the trial indicated that after a 410 day exposure to the harsh South Pole condition, the PV cells had no significant damage (Hauke, 2009). The trial array consisted of 6, 175W panels that were arranged at all orientations (Figure 9). There 6 panels generated, on average, 65kWh per week (roughly 260kWh per month)

Figure 9: The trial PV array at SPS. Adapted from Hauke, 2009.

3.6 Princess Elisabeth Station

Belgium’s Princess Elisabeth Station is a zero emission base, relying solely on wind, solar thermal and solar photovoltaic energy systems for energy. A detailed analysis of Princess Elisabeth Station is included as it will be considered an analogue for solar energy at Scott Base. Currently, Princess Elisabeth station is operating as a summer station with accommodation for up to 48 people, however it is equipped to act as a winter station also, with enough accommodation and energy available from wind turbines for 12 people to winter over (Tin, et al., 2010; International Polar Foundation, 2015).

Located at 71° 57' S, 23° 20' E, the station uses 379.5m^2 of photovoltaic panels (Figure 10) to provide nearly 47.5MWh per Austral summer season, equivalent to 32% of total energy production (PolarPower, 2012). Corresponding to the latitude of the station, the panels are positioned facing all directions (with the majority of them north facing) and are positioned at an angle of approximately 70 degrees. As Scott Base generates approximately 55MWh of energy per year from the generators (prior to the energy share), it can be assumed that by implementing a similar solar energy system as Princess Elisabeth Station would provide more than enough in the summer months (assuming that generator use is constant throughout the year, or that the generators produce approximately 27.5MWh in the summer months). Refer to section 6 for a more thorough analysis.

The panels used at Princess Elisabeth Station are Kyocera KC130GHT-2. Each panel is 0.93m^2 and rated to 130W, and has an efficiency of 16% and a maximum yield of 17V. An efficiency of 16 percent means that for every1000 Watts received per square meter, 160 Watts will be generated per square meter of panel (Dahl, N.D.).

Figure 10: Photovoltaic Panels on the roof of Princess Elisabeth Station. Source: http://www.antarcticstation.org/station/renewable_energies

4.0 ENERGY USE AND COST AT SCOTT BASE

Data was supplied from Antarctica New Zealand and summarised in Microsoft excel. The following tables illustrate the usage and cost of energy production at Scott Base. See appendices 2-5 for the original data supplied from Antarctica New Zealand.

4.1 Energy Production and Consumption

Table 1: Energy Production and Consumption at Scott Base from 1st July 2013 to 30th June 2014

SCOTT BASE ENERGY (1st July 13- 30th June 14)		
Heating Energy GENERATION	1504.4	MWh
Heating Energy CONSUMPTION	**991.13**	MWh
Electrical Energy GENERATION	913.28	MWh
Electrical Energy CONSUMPTION	**863.92**	MWh
Electrical Energy from Wind Farm	*724.89*	
Total energy Consumption per year	1855.05	MWh
Per Day	**5.082329**	MWh

Table one illustrates that, on average, Scott Base utilises 5.08MWh of energy per day. Most of that is used for heating, which is supplied from boilers running on AN8. The remaining electrical energy is supplied mostly from the Ross Island wind farm, with the remaining supplied from the generators running on AN8 fuel. The Ross Island Wind farm generates, on average, 9.12MWh electricity per day (based on data supplied by Antarctica NZ for the period January 2010-March 2014), of which 3.3MWh are used by Scott Base, with the remainder sent to McMurdo Station.

4.2 Energy Cost

Energy production in Antarctica is an expensive process, with fuel costing up to three times the original price. The energy production at Scott Base will be analysed using the most recent few years of data. In the 2013-2014 year, Scott Base used a total of over 320,000 litres of fuel for the generators (185,887L) and boilers (134,189.8L) combined. In the 2013-2014 season, the average cost of fuel for both generator and boiler fuel was $2.375 per litre, taking into account maintenance and labours costs associated with running them. The total fuel cost of running the generators and boilers works out to be approximately $760,180. The generators alone would have costed approximately $441,500. According to the Power and Fuel data spreadsheet supplied by Antarctica NZ, It was estimated that the cost per kWh of energy produced from the generators was approximately $0.57 per kWh, and the cost per kWh of wind turbine energy was on average, $0.2 per kWh. Prior to the energy share system between McMurdo and Scott Base, Scott Based used a lot less fuel for the generators. In the 2012-2013 season, Scott Base used 14878L of fuel for the generators, producing 56.1MWh. Assuming the cost of $2.35/L, the fuel used in the 2012-2013 season for the generators would have been approximately $35,000. This equates to approximately 153kWh of energy production and 40.7L of fuel per day. The CO_2 produced from this is to approximately 107.8kg of CO_2 per day. This therefore equates to 0.7kg CO_2 per kWh.

This report will focus primarily on the feasibility of implementing solar panels to minimise the use to generators. As the boilers are required for heating, the energy and fuel usage from them will not be considered.

5.0 PHOTOVOLTAIC CELLS

5.1 History of photovoltaic cells

The idea of creating electricity from solar radiation is not new. The photovoltaic effect has been known for over a century, however it was not until the 1950's that development of PV systems began to take place (Godfrey, 1996). In 1839 Becquerel noticed that specific materials produced an electric current if exposed to light. Later, in 1876 Adams and Day discovered that selenium produced electricity when exposed to light. This was the beginning of photovoltaic cell technology, with selenium photovoltaic cells converting light into electricity at approximately 1-2% efficiency (Go Solar California, 2015).

In the early 1950's, Ohl discovered that sunlight on silicon created a remarkably high current flow. The photovoltaic cell was patented in 1954 by Bell Laboratory. In 1955 Hoffman Electronics released the first commercial photovoltaic cells, which were 2% efficient. The cells cost $25 each and were 14 milliwatts each - if that were the case in today's economy, the cost would have been $1785 per watt! (Go Solar California, 2015). By 1965, photovoltaic cell efficiency was getting close to 10%, and with the increased focus on space exploration photovoltaic cell research and production increased significantly, however with the onset of worldwide hostilities it became difficult to focus on renewable energy opposed to oil.

In more recent times, enhanced technologies, lower costs and increased ease of use has made the use of photovoltaic cells more viable, with an estimated 18 terawatt hours produced per year in the United States, for example (US Energy Information Administration, 2015).

5.2 Basic Description

Photovoltaic cells consist of semiconductors, most of which are silicon. The cell will contain two types of semiconducting materials with different electric properties to obtain an electric potential. One semiconductor acts as a cathode (negative) and the other acts at an anode (positive). The negative conductor, or N-Type, has a surplus of electrons whilst the positive conductor has a deficit of electrons. Pure silicon will not provide enough electrons to create a strong current, so doping of the conductors is required. (Mason, 2007). For example, if a doping material from group V is added to the crystal lattice, than they have one too many valance electrons for the number of crystal bonds. In this case, an N-Type conductor is created, as there is a surplus of electrons. Conversely, if the silicon is doped with atoms from group III, then a deficit of electrons is created, resulting in a P-Type conductor.

The electrons of the silicon atoms give rise to the crystalline structure of the semiconductors. In a silicon atom, the highest fully occupied band of electrons is the valance band which is responsible for bonding atoms together. Silicon is in group IV of the periodic table, which means that is has four valance electrons, and therefore bonds with four other silicon atoms in the lattice (Fig. 11). The valance band of electrons is separated from the next band level (the conduction band) by the band gap. When excited, in this instance by light, electrons can move from the valance band to the conduction band which leaves behind a vacancy in the valance band. The 'hole' left behind in the valance bands represents a charge carrier. When the electrons are excited into the band gap, they become mobile and travel through the crystalline structure. Very few electrons are knocked into the band gap, which is why doping is necessary to create N-Type and P-Type conductors (Mason, 2007). (Fig. 12).

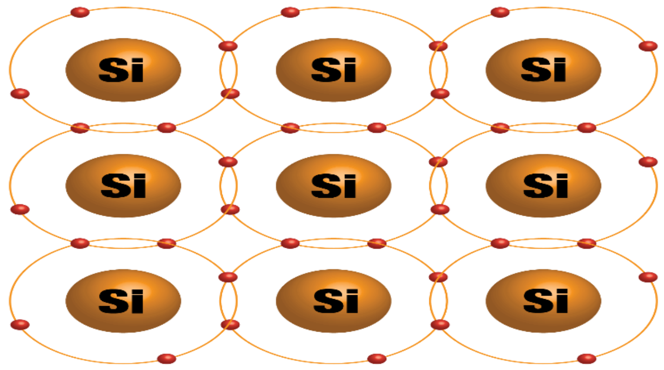

Figure 11: Silicon lattice structure. Source: http://www.redarc.com.au/images/uploads/files/silicon.png

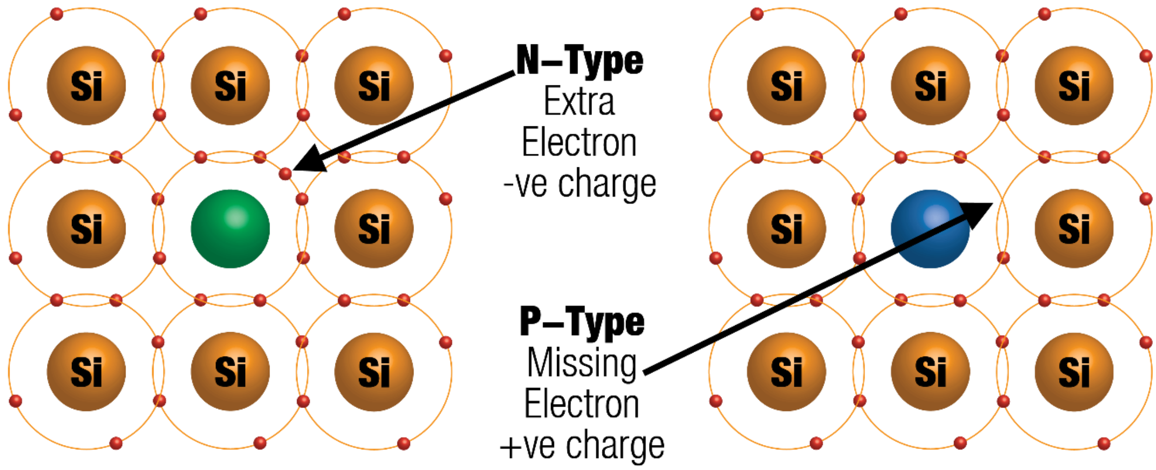

Figure 12: N-Type and P-Type conductors. Source: http://www.redarc.com.au/images/uploads/files/doped_silicon.png

When light hits the PV cell, some of the light will be absorbed into the semiconductor, and if the energy of the photons on the semiconductor is high enough it will force electrons to separate from the conductor and therefore become available for creating a current. In the junctions where there two semiconductor types meet there is a static field which acts as a guide for the electron flow, thus creating an electric current (Mason, 2007) (Figure 13).

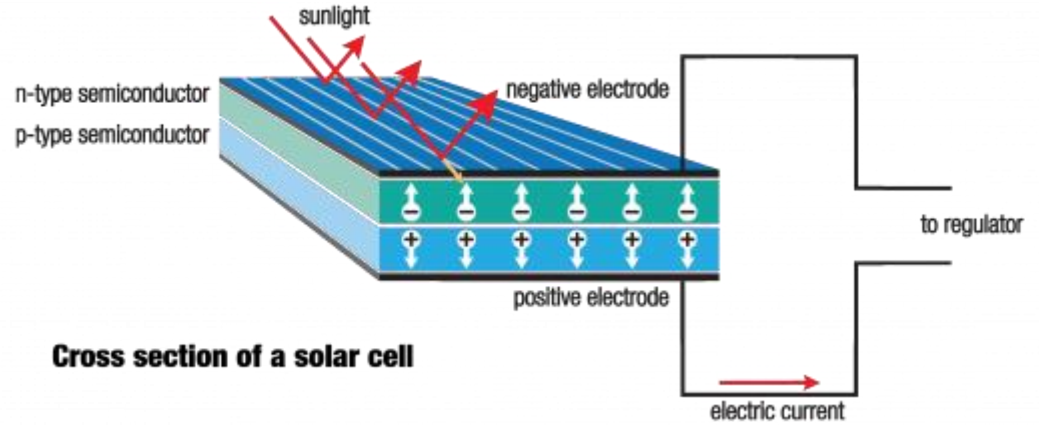

Figure 13: Cross Section of a photovoltaic cell. Source: http://www.redarc.com.au/solar/about/solarpanels/

In a photovoltaic device, electricity generation occurs when the incoming light can generate a charge by exciting electrons from the valance to conduction band, the charge can be separated (via the P-type/N-type junction and the charge can be transported (using a carrier flow within the semiconductor and electron flow through the external circuit).

6.0 ANALYSIS OF THE POTENTIAL FOR SOLAR ENERGY AT SCOTT BASE

NASA provides surface meteorological data and solar energy data that is derived from satellites. Any location can be used, defined by latitude and longitude down to the nearest degree (i.e. the data sets are available in 1° by 1° grids) (NASA, 2015). The data sets provide a 22 year average of solar radiation at any given location (Table 2). NIWA also provides data for solar radiation at Scott Base, however the data sets contain numerous gaps and data is only available from 1999.

Once the global radiation data is known it is possible to calculate the energy production from a given number of panels. By basing the design from Princess Elisabeth Station, a total of 408 panels is used in the following calculations. This equates to approximately 380m^2 of photovoltaic panels (1 panel is 0.93m^2). By using equation 1, the potential energy production was calculated and presented in Table 2.

Equation 1:

Watts = Global Radiation x Panel Power x Dirt Factor x Manufacturer Factor x Inverter Efficiency x Cable Losses x Peak Sun Hours x Number of Panels x Days in Month

Where:

Global Radiation is the total amount of solar radiation received at an equator tilted surface at 77°; Panel Power the manufacturers power rating; Dirt Factor is losses due to dirt accumulation on the panels; Manufacturer factor is losses due to small inaccuracies with manufacturers ratings; Inverter efficiency is losses to the inverters; Cable Losses are losses from the cables; Peak Sun Hours is identical to global radiation. (Phil Arnold, personal communication, 8th Jan, 2015).

Table 2: Total potential energy production from 408 panels for the months September through to March

Month	Global Radiation (kWh/m²/day)	Panel Power (W)	Dirt factor	Manufacturer factor	Inverter efficiency	Cable Losses	Peak Sun Hours	No. Panels	Days in Month	Watts	kWh	MWh
Sept	2.15	130	0.85	0.97	0.96	0.98	2.15	408	30	2653696.2	2653.7	2.7
Oct	4.36	130	0.85	0.97	0.96	0.98	4.36	408	31	5560830.6	5560.8	5.6
Nov	5.1	130	0.85	0.97	0.96	0.98	5.1	408	30	6294814.2	6294.8	6.3
Dec	6.01	130	0.85	0.97	0.96	0.98	6.01	408	31	7665273.4	7665.3	7.7
Jan	5.48	130	0.85	0.97	0.96	0.98	5.48	408	31	6989300.9	6989.3	7.0
Feb	3.94	130	0.85	0.97	0.96	0.98	3.94	408	28	4538849.0	4538.8	4.5
Mar	3.04	130	0.85	0.97	0.96	0.98	3.04	408	31	3877276.4	3877.3	3.9
											Total	**37.6**

Table 2 demonstrates that with 480 photovoltaic panels tilted at 77° (Fig. 14) it is possible to generate approximately 37.6 MWh between September and March. This is likely to be enough to minimise the use of generators at Scott Base in the summer months, however due to the difficulties associated with storage of power, the energy generated from the PV system would need to be fed directly in the Ross Island electrical grid, shared between New Zealand and the United States, as it is not possible to feed the power directly and only to Scott Base (Phil Arnold, personal communication, 8th Jan, 2015). The power generated by the PV array could be purchased from the United States, and minimise their dependency on generator use as well. This has been proven to work already, with the same situation occurring with the Ross Island Wind Farm.

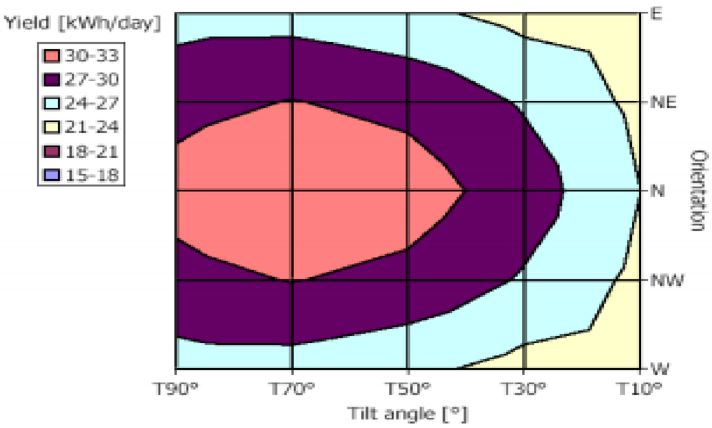

Figure 14: The yield of energy based on the tilt of the panels and orientation. Based on Princess Elisabeth Station which is situated at approximately71°S. Adapted from Van Rattinghe, 2008.

Figure 13 illustrates that for a photovoltaic array situated at 71°S, a North orientation and tilt of 71° will yield the most amount of energy. At Scott Base, a tilt of 77° and North orientation is therefore ideal.

Many factors have not been included in these calculations, such as albedo, temperature and degradation of the PV cells over time. It is estimated that photovoltaic cells degrade approximately

20% every 25 years (Phil Arnold, personal communication, 8th Jan, 2015). The actual energy production is likely to be higher than specified, due to the higher performance in colder temperatures. The estimation that solar panels perform approximately 20% better in the Antarctic was not been included in the calculations, however, when taken into consideration the power generation is likely to be approximately 46.5MWh from September to March (Table 3).

Table 3: Total potential energy production from 408 panels for the months September through to March with a manufacturers factor of 1.2

Month	Global Radiation	Panel Power	Dirt factor	Manufacturer factor	Inverter efficiency	Cable Losses	Peak Sun Hours	No. Panels	Days in Month	Watts	kWh	MWH
Sept	2.15	130	0.85	1.2	0.96	0.98	2.15	408	30	3282923.1	3282.9	3.3
Oct	4.36	130	0.85	1.2	0.96	0.98	4.36	408	31	6879378.1	6879.4	6.9
Nov	5.1	130	0.85	1.2	0.96	0.98	5.1	408	30	7787399.0	7787.4	7.8
Dec	6.01	130	0.85	1.2	0.96	0.98	6.01	408	31	9482812.5	9482.8	9.5
Jan	5.48	130	0.85	1.2	0.96	0.98	5.48	408	31	8646557.8	8646.6	8.6
Feb	3.94	130	0.85	1.2	0.96	0.98	3.94	408	28	5615071.0	5615.1	5.6
Mar	3.04	130	0.85	1.2	0.96	0.98	3.04	408	31	4796630.6	4796.6	4.8
											Total	**46.5**

It is recommended that the Kyocera KC130GHT-2 panels are used due to their proven effectiveness at Princess Elisabeth Station. These cells are designed for harsh weather environments, with reinforced glass covering the cells designed to withstand intense hailstorms. They are also covered with an EVA (ethylene-vinyl-acetate) foil and are sealed with a PET (Polyethylene terephthalate) foil. They are also set in a very sturdy aluminium frame (Kyocera, 2007).

As presented earlier in this report, energy from the generators equates to approximately 0.70kg of CO_2 per kWh. If the PV array was implemented and operated at peak levels (i.e. 46.5MWh September-March), a total of 32.2 tonnes of CO_2 emissions would be eliminated.

6.2 Suggested layout

Given the lack of ice free land on Ross Island and the shaded position of Scott Base, a suitable location for the PV array is difficult to identify. A suggested array is presented in figure 15 below. Each red line represents an array of 102 panels, and each yellow line represents 51 panels.

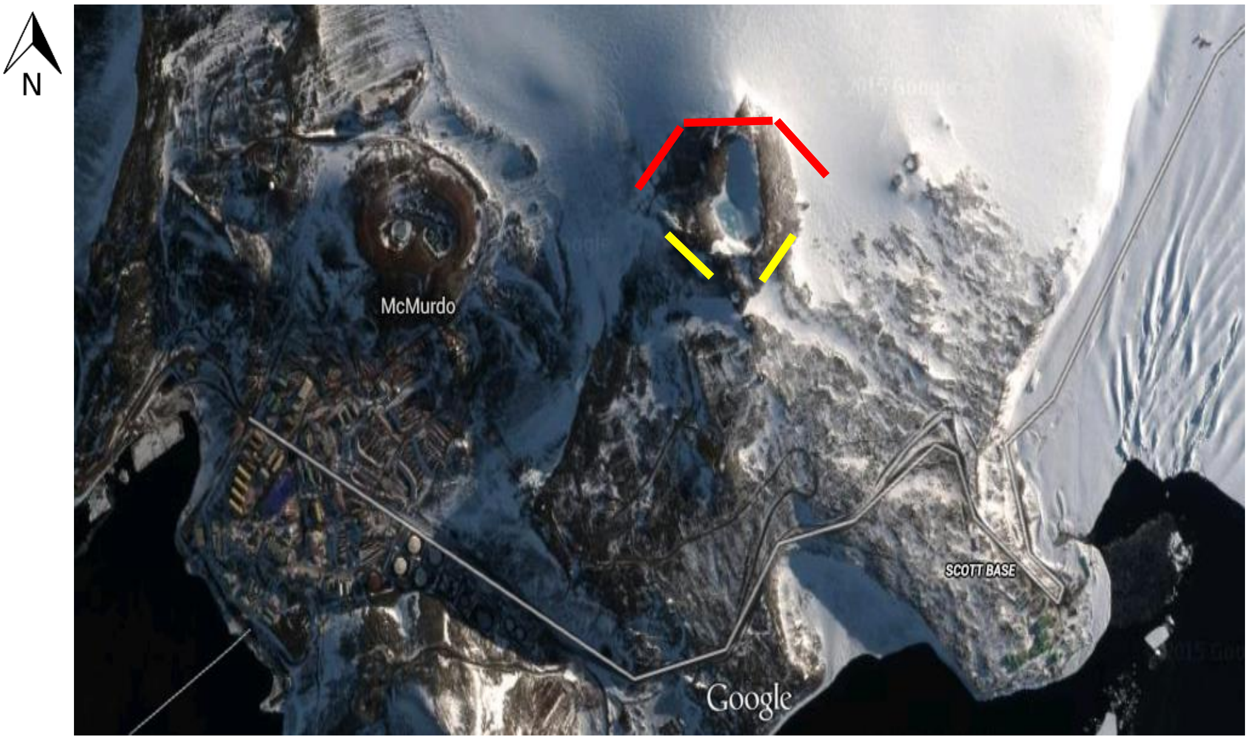

Figure 15: Suggested solar array layout with the majority in a north facing direction. Adapted from google maps. Not to scale.

As is presented in figure 14, Scott Base is often in the shadows of Crater Hill, and it is therefore recommended that the PV array should be installed in an area that will not be in the shadows for much of the day (particularly in early and late summer when the sun is not as high in the sky). The North facing rim of Crater Hill is an ideal location for a PV array, as there is nothing that would obstruct sunlight. It is suggested that the majority of the panels are oriented towards the north to ensure maximum yield. In addition, the majority of electrical requirements are during the 'day' hours, when the sun is in the north.

6.3 Cost Analysis

N.B. This cost analysis is a non-exhaustive analysis for the materials cost only, and should therefore be taken as a very rough estimate. Costs involved with transport, labour, securing of the panels into the ground, cables/wiring and maintenance will not be included. Furthermore, small structures to house the 10kW inverters will be required, and are not included in this analysis. This cost analysis is also based on the fuel use for the generators prior to the energy share arrangement with McMurdo. Fuel use is significantly higher since the energy share arrangement was made (appendix 4).

It has been estimated that the cost of solar equates to approximately $4 USD per watt (Dahl, N.D.) With 408, 130 Watt panels installed, this equates to approximately $212,000USD (approx. $281,000 NZD). The cost of the brackets to hold the panels are estimated to cost roughly $3,500NZD. 6x 10kW inverters would be required (the array for 408panels is a 53kW system) which are priced at approximately $3300 each, bringing the total to $19800 for the inverters (SMA German made). It is likely that the overall cost of the materials, transport and labour would exceed $500,000. However, given the cost of running the generators ($35,000 in the 2012/2013 season), it is likely that the array would pay for itself with time. Assuming that the generators run equally throughout the year, it can be concluded that in the summer months half of the annual generator fuel is used, equating to approximately $17,500. Assuming an initial costs of $500,000, the payback time is expected to be within 20-30 years. With current technology, this is likely to be the lifetime of the panels. As the power generated from the PV array cannot be fed directly to Scott Base, the United States Antarctic Program (McMurdo) could be purchasing the energy that it is using, a similar situation to the Ross Island Wind Farm. It is likely that the panels would therefore pay for themselves within their lifetime of operation.

7.0 SOLAR POWER AT FIELD CAMPS

As field camps are powered mostly by generators at this stage, the use of photovoltaic cells could be very feasible. A short analysis of the use of solar technology to power the Cape Bird hut is presented below.

Cape Bird is a narrow strip of rocky coast at the base of Mt Bird, on the Northwest corner of Ross Island (77.22°S 166.43°E). At Cape Bird, a small hut that can facilitate 8 people is used throughout the summer months. The hut consists of 2 bunk rooms, a kitchen and dining area, store room and small laboratory (Hume, 2004). Generally, the hut is occupied from mid- October until February.

Based on Hume (2004), it is assumed that the field hut uses approximately 2kWh of energy per day for electrical items and fittings (i.e. lights, fridge, laptops and cleaning utilities). This is assuming that the load is slightly higher than in 2004, when it was approximately 1.8kWh. If the load has decreased, then the worst case scenario is a slightly over-powered field camp. For the purpose of this analysis space heating will not be included. The following calculations are based on solar radiation data from Scott Base, and assume that the panels are tilted at 77°.

Based on a daily usage of 2kWh, the field camp would use approximately 62kWh per month. Presented in Table 4 is the projected energy production from 5 panels (4.65m^2) from September through to March. The panels that table 5 is based on are the Kyocera KC130GHT-2 panels, presented earlier in this report and used at Princess Elisabeth Station.

Table 4: Total potential energy production from 5 panels for the months September through to March with a manufacturers factor of 0.97

Month	Global Radiation	Panel Power	Dirt factor	Manufacturer factor	Inverter efficiency	Cable Losses	Peak Sun Hours	No. Panels	Days in Month	Watts	kWh
Sept	2.15	130	0.85	0.97	0.96	0.98	2.15	5	30	32520.8	32.5
Oct	4.36	130	0.85	0.97	0.96	0.98	4.36	5	31	68147.4	68.1
Nov	5.1	130	0.85	0.97	0.96	0.98	5.1	5	30	77142.3	77.1
Dec	6.01	130	0.85	0.97	0.96	0.98	6.01	5	31	93937.2	93.9
Jan	5.48	130	0.85	0.97	0.96	0.98	5.48	5	31	85653.2	85.7
Feb	3.94	130	0.85	0.97	0.96	0.98	3.94	5	28	55623.1	55.6
Mar	3.04	130	0.85	0.97	0.96	0.98	3.04	5	31	47515.6	47.5

From Table 4 it is clear that by using only 5 Kyocera panels, enough energy could be supplied to power appliances and lighting within the hut. Table 4 assumes a manufactures factor of 0.97 when in reality it is likely to be closer to 1.2 due to the colder temperatures in Antarctica (manufacturers factor is based on a temperature of 25°C). Table 5 presents the results with a manufacturers factor of 1.2, which is likely to be more representative of what would be achieved in the Antarctic.

Table 5: Total potential energy production from 5 panels for the months September through to March with a manufacturers factor of 1.2

Month	Global Radiation	Panel Power	Dirt factor	Manufacturer factor	Inverter efficiency	Cable Losses	Peak Sun Hours	No. Panels	Days in Month	Watts	kWh
Sept	2.15	130	0.85	1.2	0.96	0.98	2.15	5	30	40231.9	40.2
Oct	4.36	130	0.85	1.2	0.96	0.98	4.36	5	31	84306.1	84.3
Nov	5.1	130	0.85	1.2	0.96	0.98	5.1	5	30	95433.8	95.4
Dec	6.01	130	0.85	1.2	0.96	0.98	6.01	5	31	116210.9	116.2
Jan	5.48	130	0.85	1.2	0.96	0.98	5.48	5	31	105962.7	106.0
Feb	3.94	130	0.85	1.2	0.96	0.98	3.94	5	28	68812.1	68.8
Mar	3.04	130	0.85	1.2	0.96	0.98	3.04	5	31	58782.2	58.8

Table 2 demonstrates that with just 5 panels ($4.65m^2$), more than enough energy would be supplied to power appliances and lighting at the hut.

8.0 RECOMMENDATIONS

8.1 Scott Base

Whilst it is certainly possible to make use of solar energy at Scott Base, this report has found that it is not feasible for Scott Base for the following reasons

- Cost – whilst a PV array may be able to pay for itself within its working lifetime, the initial costs associated with materials, labour and logistics are not feasible
- Efficiency – The Ross Island wind farm generates more power (on average) in 2 days than a $380m^2$ PV array would for all of December
- Space - a wind turbine requires approximately 5-10m of ground space, opposed to hundreds of square meters for a PV array
- Location - There are not many locations that are suitable for a PV array at or near Scott Base
- Power share with McMurdo – As the energy created would be shared with McMurdo, Scott Base would still be running the generators. There are currently no feasible energy storage options available to store such a large amount of energy, and the energy would have to be fed into the Ross Island Electrical Grid.

For the above reasons the use of large scale photovoltaic energy systems at Scott Base is not recommended. It is recommended that further investigations into solar thermal and hot water heating is undertaken, as these may be viable options for Scott Base to minimise its fuel use and cost and impact on the environment.

A trial PV array could be installed on the north facing roofs of Scott Base to supply some of the power for appliances and lighting and to further investigate the use of PV arrays at Scott Base.

8.2 Field Camps

Given the effectiveness of solar panels in the Antarctic summer, a trial at Cape Bird is highly recommended to ensure the feasibility before implementing on other field camps. It should also be noted that the vast majority of energy (63% in New Zealand homes) is used for hot water and space heating. Therefore investigations into solar water heating and solar space heating is recommended. The United States Antarctic Program has used solar power successfully at Lake Hoare, in the Dry Valleys. The field hut there can accommodate up to 16 people and makes use of a 1.5kW solar array that is manually tracked. Given the advances in technology since its implementation in 1992, it is clear that solar energy is effective for field camps. The Lake Hoare field camp still makes use of a generator, however it is rarely used for more than 30 hours in a season (Mason, 2006).

8.3 Tracking Systems

Tracking systems ensure that the photovoltaic array is continuously pointed towards the sun, achieving maximum insolation for the array. There are a few types of trackers such as 1-D and 2-D systems. 1-D trackers simply change either the orientation (North, South, East or West) or the angle of the panels (changing one and keeping the other fixed). 2-D trackers change both the angle and the orientation which ensures that the array is always facing directly toward the sun. These systems are extremely costly and complicated and it is more feasible to simply install more panels facing different directions, on different angles (Mason, 2007).

8.4 Other Recommendations

Investigations into solar space heating and solar hot water heating are recommended. Solar heating collectors have existed for centuries in various different forms and the newest technologies have proved effective in the Antarctic summer. Solar hot water system are used at Australia's Davis station, and currently provides 100% of the hot water required for personal and laundry use in the summer, where the station has up to 125 people in the summer (Mason, 2006; AAD, 2014). Princess Elisabeth Station makes use of passive and active solar energy, to heat space and water. Currently, 100% of heating and hot water is supplied via solar thermal collectors (International Polar Foundation, 2008).

9.0 CONCLUSIONS

The use of photovoltaic technology is certainly a possibility in the Antarctic, with an Antarctic summer providing more solar energy than a Dutch summer! Calculations indicate that with an array of 408 photovoltaic panels, up to 46.5MWh of energy could be generated at Scott Base between September and March. This would result in a reduction of CO_2 emissions by approximately 32.2 tonnes. Whilst this is a significant quantity of energy and the payback time is within the lifetime of the photovoltaic cells, it is not a feasible option for Scott Base.

I was found that wind energy is a much more viable option, and has proved to be a success for Scott Base. It is suggested that more wind turbines are introduced to Ross Island to further minimise fuel use for power generation. It is also suggested that thorough investigations into the use of solar thermal and solar hot water systems is undertaken.

Field camps could benefit from the use of photovoltaic cells, as has been shown in the study into the Cape Bird hut. Portable PV panels are already used by Scott Base field camps. Generators are still taken on many field camps, but it is suggested that more use of PV panels could be a very feasible option for power supply.

Antarctica New Zealand are leaders in sustainable operations in the Antarctic, and any methods available to minimise their impact on the environment should be considered. In accordance with Article 3 of the environmental protocol suggests, and in accordance with Antarctica New Zealand's commitment towards environmental stewardship, further investigations into renewable energy resources is advised.

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APPENDICES

Appendix 1: Article 3 of the Environmental Protocol

“ARTICLE 3 ENVIRONMENTAL PRINCIPLES

The protection of the Antarctic environment and dependent and associated ecosystems and the intrinsic value of Antarctica, including its wilderness and aesthetic values and its value as an area for the conduct of scientific research, in particular research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area.

2. To this end:

(a) activities in the Antarctic Treaty area shall be planned and conducted so as to limit adverse impacts on the Antarctic environment and dependent and associated ecosystems;

(b) activities in the Antarctic Treaty area shall be planned and conducted so as to avoid: (i) adverse effects on climate or weather patterns; (ii) significant adverse effects on air or water quality; (iii) significant changes in the atmospheric, terrestrial (including aquatic), glacial or marine environments; (iv) detrimental changes in the distribution, abundance or productivity of species or populations of species of fauna and flora; (v) further jeopardy to endangered or threatened species or populations of such species; or (vi) degradation of, or substantial risk to, areas of biological, scientific, historic, aesthetic or wilderness significance;

(c) activities in the Antarctic Treaty area shall be planned and conducted on the basis of information sufficient to allow prior assessments of, and informed judgments about, their possible impacts on the Antarctic environment and dependent and associated ecosystems and on the value of Antarctica for the conduct of scientific research; such judgments shall take account of: (i) the scope of the activity, including its area, duration and intensity; (ii) the cumulative impacts of the activity, both by itself and in combination with other activities in the Antarctic Treaty area; (iii) whether the activity will detrimentally affect any other activity in the Antarctic Treaty area; (iv) whether technology and procedures are available to provide for environmentally safe operations; (v) whether there exists the capacity to monitor key environmental parameters and ecosystem components so as to identify and provide early warning of any adverse effects of the activity and to provide for such modification of operating procedures as may be necessary in the light of the results of monitoring or increased knowledge of the Antarctic environment and dependent and associated ecosystems; and (vi) whether there exists the capacity to respond promptly and effectively to accidents, particularly those with potential environmental effects;

(d) regular and effective monitoring shall take place to allow assessment of the impacts of ongoing activities, including the verification of predicted impacts;

(e) regular and effective monitoring shall take place to facilitate early detection of the possible unforeseen effects of activities carried on both within and outside the Antarctic Treaty area on the Antarctic environment and dependent and associated ecosystems.

3. Activities shall be planned and conducted in the Antarctic Treaty area so as to accord priority to scientific research and to preserve the value of Antarctica as an area for the conduct of such research, including research essential to understanding the global environment.

4. Activities undertaken in the Antarctic Treaty area pursuant to scientific research programmes, tourism and all other governmental and non-governmental activities in the Antarctic Treaty area for which advance notice is required in accordance with Article VII (5) of the Antarctic Treaty, including associated logistic support activities, shall: (a) take place in a manner consistent with the principles in this Article; and (b) be modified, suspended or cancelled if they result in or threaten to result in impacts upon the Antarctic environment or dependent or associated ecosystems inconsistent with those principles."

Appendix 2: Ross Island Wind Farm energy production raw data from Antarctica NZ.

Month	Average Wind Speed (Actual)	Average Wind Speed (Forecast)	Average Wind Speed Difference (Actual - Forecast)	Wind Farm Energy Output (Actual) (kWhr)
Jan-10	6.17	6.40	-0.23	-
Feb-10	8.67	7.60	1.07	284,357
Mar-10	9.03	8.00	1.03	332,173
Apr-10	7.90	7.30	0.60	278,005
May-10	7.71	7.90	-0.19	161,427
Jun-10	7.07	8.90	-1.83	241,263
Jul-10	8.57	7.90	0.67	222,918
Aug-10	9.10	8.60	0.50	212,222
Sep-10	9.13	9.20	-0.07	140,808
Oct-10	6.87	8.00	-1.13	240,528
Nov-10	7.23	7.20	0.03	226,982
Dec-10	6.93	6.30	0.63	233,496
Jan-11	6.57	6.40	0.17	175,892
Feb-11	7.97	7.60	0.37	296,167
Mar-11	8.37	8.00	0.37	378,937
Apr-11	8.76	7.30	1.46	278,046
May-11	7.70	7.90	-0.20	261,452
Jun-11	9.37	8.90	0.47	316,299

Jul-11	10.10	7.90	2.20	314,603
Aug-11	8.40	8.60	-0.20	326,651
Sep-11	10.40	9.20	1.20	275,216
Oct-11	7.87	8.00	-0.13	314,871
Nov-11	7.83	7.20	0.63	302,813
Dec-11	6.73	6.30	0.43	232,057
Jan-12	6.17	6.40	-0.23	190,728
Feb-12	8.00	7.60	0.40	309,990
Mar-12	8.20	8.00	0.20	354,835
Apr-12	7.80	7.30	0.50	314,311
May-12	10.03	7.90	2.13	346,129
Jun-12	8.43	8.90	-0.47	289,206
Jul-12	7.73	7.90	-0.17	203,160
Aug-12	9.50	8.60	0.90	339,441
Sep-12	8.20	9.20	-1.00	311,619
Oct-12	7.60	8.00	-0.40	244,751
Nov-12	7.07	7.20	-0.13	244,365
Dec-12	6.13	6.30	-0.17	195,281
Jan-13	6.43	6.40	0.03	182,749
Feb-13	7.90	7.60	0.30	285,223
Mar-13	8.20	8.00	0.20	295,566
Apr-13	7.97	7.30	0.67	200,296
May-13	9.57	7.90	1.67	409,726
Jun-13	9.03	8.90	0.13	339,568
Jul-13	8.03	7.90	0.13	256,551
Aug-13	8.83	8.60	0.23	321,983
Sep-13	8.37	9.20	-0.83	313,374
Oct-13	7.40	8.00	-0.60	282,382
Nov-13	7.23	7.20	0.03	258,996
Dec-13	5.93	6.30	-0.37	156,759
Jan-14	6.17	6.40	-0.23	196,360
Feb-14	8.57	7.60	0.97	347,024
Mar-14	9.50	8.00	1.50	458,526
Apr-14	7.50	7.30	0.20	236,272
May-14	9.73	7.90	1.83	290,286

Appendix 3: Energy consumption and generation data for Scott Base. Raw Data from Antarctica NZ.

Period 1 July 2013 to 30 June 2014									
				Initial	**Final**	**Meter Total for Year**		**Building Total by Year**	
						(MWh)		**(MWh)**	
Heating Energy Generation									
	BD07			189176	253895	647.19		647.19	
	BD09			203002	251944	489.42		489.42	
	BD11			1388357	1756147	367.79		367.79	
								1504.40	MWh
Heating Energy Consumption by Building									
	BD01			158157	184092	25.94		25.94	
	BD02/BD04			316806	361460	44.65		44.65	
	BD03			318680	372347	53.67		53.67	
	BD05			276586	331555	54.97		54.97	
	BD06 Bar			15988	23008	7.02			
	BD06 Mess			313206	382854	69.65		92.55	
	BD06 Drying Rm			75249	91132	15.88			
	BD07			530883	794089	263.21		263.21	
	BD08			229200	280901	51.70		51.70	
	BD09			120151	134207	14.06		14.06	
	BD10 General			71772	94372	22.60		111.98	
	BD10 Underfloor (from BD11)			400818	490201	89.38			
	BD11							278.41	
								991.13	MWh
Electrical Energy Generation									
	BD07 GE01			221.7	420.28	198.58		198.58	
	BD07 GE02			208.51	380.28	171.77		171.77	
	BD09 GE01			316.22	369.66	53.44		53.44	
	BD07 Grid Import			391677	1116565	724.89		724.89	
	BD07 Grid Export			10417	245812	-235.40		-235.40	
								913.28	MWh
Electrical Energy Consumption by Building									
	BD01			638.13	768.62	130.49		130.49	
	BD02			171.66	219.32	47.66		47.66	
	BD03			35.38	53.95	18.57		18.57	
	BD04			75.42	97.85	22.43		22.43	
	BD05			272.51	342.78	70.27		70.27	

	BD06			182.28	232.74	50.46		50.46	
	BD07 Power House			70.48	85.92	15.44		90.56	
	BD07 MCC			286.64	361.76	75.12			
	BD08			190.15	243.02	52.87		52.87	
	BD09 General			235.45	282.15	46.70		92.02	
		BD09 Main HR		92.82	120.61	27.79			
	BD09 MCC			132.48	177.8	45.32			
	BD10			365.54	467.04	101.50		101.50	
		BD10 Front/Rear HR		53.15	73.54	20.39			
	BD11			498.63	621.48	122.85		122.85	
	Wet Labs			246.16	310.4	64.24		64.24	
								863.92	MWh

Appendix 4: Scott Base boiler and generator fuel use. Raw data from Antarctica NZ.

BOILER FUEL (l)								
			2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
11	NOV		5744.48276	2304.9	10535	11036	12944	14093.4
12	DEC		3056	5800.9	8496	9543	10438	11803.6
1	JAN		3,083.00	7,960.70	8,942.00	11,138.00	10,014.00	10,727.50
2	FEB		7,129.00	10,326.30	12,067.00	12,405.00	11,391.00	8,366.30
3	MAR		10,356.10	12,950.30	17,117.00	15,918.00	14,500.00	13,249.40
4	APR		10,369.50	14,774.00	17,867.00	15,641.00	19,269.00	9,741.20
5	MAY		12,916.00	15,340.20	17,918.00	15,886.00	17,661.00	12,591.90
6	JUN		12,080.30	16,784.00	16,060.00	19,672.00	17,445.00	10,315.00
7	JUL		14,146.40	15,333.00	17,629.00	19,313.00	22,468.87	15,197.20
8	AUG		14,934.80	18,432.00	17,329.00	19,950.00	27,103.00	8,520.50
9	SEP		11,974.30	17,619.00	18,462.00	18,288.00	16,855.00	8,316.40
10	OCT		7,020.80	15,033.00	17,210.40	16,655.00	16,329.50	11,267.36
			112,810.68	152,658.30	179,632.40	185,445.00	196,418.37	134,189.76

GEN FUEL (l)								
			2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
11	NOV		23524.14	24447	143	441	730	622
12	DEC		21238	15529	733	546	417	586
1	JAN		20827	7125	2416	210	1781	628.4
2	FEB		18871	1213	456	2317	332	12488.3
3	MAR		23210	1556	912	2136	614	14966.3
4	APR		21619	1189	409	1635	60	33511
5	MAY		22615	5157	809.44	1016	1187	17784
6	JUN		21711	1041	905.11	210	3242	30931
7	JUL		22453.5	6603	421.66	217	4456	22043
8	AUG		22371	836	459.79	656	905	22415

9	SEP		23733	784	476	402	548	19250
10	OCT		26233	2994	491	974	606	10662
			268405.6	68474	8632	10760	14878	185887

Appendix 5: Energy generation from generators by year. Raw data from Antarctica NZ.

GEN POWER (kWH)					
		2010-11	2011-12	2012-13	2013-14
11	NOV	817	1,900	3,640	2,674
12	DEC	3,242	2,478	1,156	1,329
1	JAN	8,845	1,016	4,971	2,109
2	FEB	1,952	8,586	1,476	45,469
3	MAR	7,600	8,709	2,450	58,390
4	APR	1,392	5,920	531	
5	MAY	5,681	4,743	5,121	
6	JUN	2,311	514	12,343	
7	JUL	1,969	1,147	16,208	
8	AUG	2,021	2,717	3,718	
9	SEP	2,555	1,787	1,822	
10	OCT	2,129	4,050	2,674	
		40,515	43,567	56,110	